

Scanning electron microscopy evaluation of external surface defects in different nickel-titanium endodontic instruments

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Abstract

The aim of this study was to evaluate the presence and relevance of surface defects in each of five widely used NiTi systems: I-File (Henry Schein Endodontics, which is also commercialized as Onyx, EdgeEndo, USA), Mtwo (Sweden Martina, Italy), WaveOne Gold (Dentsply, USA) Reciproc Mwire, and Reciproc Blue (VDW, Germany). Each group uses a different type of alloy and manufacturing procedures, with differences in manufacturing and metallurgy that might yield observable differences in surface defect profiles. The null hypothesis tested was that there would be no significant difference in the prevalence or severity of external surface defects among the five brands, nor between heat-treated and non-heat-treated instruments. SEM imaging was performed using a scanning electron microscope (Quanta FEG 400, FEI, USA) at 100×, 500×, and 1000× magnification. Data were collected and statistically analyzed. Intergroup comparisons were performed using the Kruskal–Wallis test. Pairwise comparisons were adjusted with Bonferroni correction. Significance was set at $\alpha = 0.05$. All instrument groups exhibited some degree of external surface irregularities, predominantly machining grooves and minor pits. Microcracks and protrusions were less frequent. No statistically significant differences were detected among the five brands for any defect category or total score. More precise statistical analysis revealed no significant differences among the five instrument systems in total surface defect scores ($H(4) = 1.32$, $p = 0.86$). Similarly, individual defect categories, including machining grooves, pits, microcracks, protrusions, and irregularities, did not differ significantly between brands ($p > 0.05$ for all comparisons). Across all systems, most defects were minor (score 1), with very few severe defects (score 3). No instrument exhibited severe microcrack scores >1 . Within the limitations of this SEM analysis, the five NiTi instrument brands (I-File/Onyx, Mtwo, Reciproc Mwire, Reciproc Blue, and WaveOne Gold) demonstrated comparable external surface integrity, regardless of the grinding device or heat treatment.

Keywords: Nickel titanium, instruments, surface defects, grinding

Introduction

The introduction of Nickel-Titanium (NiTi) rotary and reciprocating instruments has revolutionized modern endodontics by offering greater flexibility and cutting efficiency than stainless steel files. This fundamental transition, initiated by the pioneering studies of Walia et al. (1988), enabled the management of complex canal curvatures with a reduced risk of apical transportation (1). However, as highlighted by Peters (2004),



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How to Cite

Gianluca Gambarini, Massimo Galli, Maya Feghali, Raffaella Castagnola, Nicola Maria Grande.

Scanning electron microscopy evaluation of external surface defects in different nickel-titanium endodontic instruments.

Annali Di Stomatologia, 17(1)62-68.
<https://doi.org/10.59987/ads/2026.1.62-68>

root canal system preparation remains one of the most arduous challenges due to anatomical variability and the mechanical limitations of instrumentation (2).

Instrument fracture remains a clinical concern, often attributed to cyclic fatigue and torsional stresses during root canal shaping. Sattapan et al. (2000) highlighted that torsional stress is prevalent when the tip becomes locked. In contrast, cyclic fatigue, described by Pruett et al. (1997), is strictly correlated with the radius and angle of canal curvature (3, 4).

External surface defects (including microcracks, pits, and irregular machining marks) are hypothesized to act as stress concentrators, potentially contributing to premature instrument failure during clinical use (5,6). Supporting this, Alapati et al. (2005) and Lopes et al. (2010) demonstrated that cracks often originate precisely from surface imperfections, propagating within the alloy until catastrophic failure (7, 8).

Scanning electron microscopy (SEM) has become an indispensable tool for qualitatively and quantitatively assessing the surface topography of endodontic instruments at high resolution. Arantes (2014) provided a classification scheme for external defects observed in ground NiTi instruments, including pits, fractures, grooves, and material irregularities, offering a basis for systematic evaluation (9).

Contemporary instruments incorporate various heat treatments and proprietary metallurgy, such as Mwire, Blue treatment, Gold treatment, and controlled memory (CM) wire, which aim to enhance flexibility and mechanical resistance. Shen et al. (2013) clarified that the martensitic phase induced by these treatments confers unique shape recovery and ductility properties (10). Given the diversity of manufacturing processes, it is clinically relevant to assess whether these instruments differ in baseline surface integrity before use.

This study aimed to apply a similar defect classification to that used by Arantes (9) to 18 new instruments from each of five widely used NiTi systems: I-File (Henry Schein Endodontics, which is also commercialized as Onyx, EdgeEndo, USA), Mtwo (Sweden Martina, Italy), WaveOne Gold (Dentsply, USA), Reciproc Mwire and Reciproc Blue (VDW, Germany). Each group has a different type of alloy and manufacturing procedures. We hypothesized that differences in manufacturing and metallurgy might yield distinct surface defect profiles. The null hypothesis tested was that there would be no significant difference in the prevalence or severity of external surface defects among the five brands, nor between heat-treated and non-heat-treated instruments.

Materials and Methods

A total of 90 new NiTi endodontic instruments were evaluated, consisting of 18 instruments for each of the five brands:

Brand	Number of Instruments	Alloy / Treatment
I-File	18	Conventional NiTi
Mtwo	18	Conventional NiTi

Brand	Number of Instruments	Alloy / Treatment
Reciproc M-wire	18	Mwire heat-treated NiTi
Reciproc Blue	18	Blue heat-treated NiTi
Wave One Gold	18	Gold heat-treated NiTi

Instruments were selected at random from new, sealed, sterile packages, representing the most commonly used sizes for each system (e.g., size 25/.06 for rotary systems and corresponding sizes for reciprocating files).

SEM Preparation

Each instrument was ultrasonically cleaned in ethanol for 5 minutes, rinsed in deionized water, and air-dried. Instruments were then mounted on aluminum stubs using carbon adhesive tabs, ensuring consistent orientation of shafts and cutting flutes. SEM imaging was performed using a scanning electron microscope (Quanta FEG 400, FEI, USA) at 100×, 500×, and 1000× magnification, with an accelerating voltage of 15 kV. The imaging procedure followed standard guidelines for SEM examination of metallic surfaces, as outlined in ASTM E986-04, to ensure the reproducibility of observations (11). Instrument surfaces were systematically imaged along the apical, middle, and coronal thirds of each file.

Surface defects were categorized following an adapted version of Arantes' classification:

- 1. Machining grooves (MG):** linear marks from manufacturing.
- 2. Pits (P):** localized depressions or voids.
- 3. Microcracks (MC):** fine cracks on the surface.
- 4. Protrusions (PR):** raised irregularities.
- 5. Irregularities (IR):** non-uniform areas not attributable to standard machining.

Each defect type was scored per instrument according to the following severity index:

Score	Description
0	No defect
1	Minor (superficial)
2	Moderate (pronounced but non-continuous)
3	Severe (deep or continuous)

The total defect score per instrument was the sum of the individual defect type scores (range 0–15).

Statistical Analysis

Defect frequencies and severity scores were analyzed using SPSS v27. Data are presented as mean ± standard deviation (SD). Normality was assessed with Shapiro-Wilk tests. Because the data did not meet parametric assumptions, a nonparametric analysis was conducted, in accordance with the recommendations of Conover

(1999) for the analysis of ordinal and non-normally distributed data (12). Furthermore, as suggested by Field (2018), robust tests such as the Kruskal–Wallis test are preferable for moderate sample sizes with skewed distributions (13). Intergroup comparisons were performed using the Kruskal–Wallis test. Pairwise comparisons were adjusted with Bonferroni correction. Significance was set at $\alpha = 0.05$.

Results

Overall Defect Profiles are shown in Tables 1–4. All instrument groups exhibited some degree of external surface irregularities, predominantly machining grooves and minor pits. Microcracks and protrusions were less frequent. Representative SEM images are shown in

Figures 1, 2, 3, 4, and 5. No statistically significant differences were detected among the five brands for any defect category or total score. More precise statistical analysis revealed no significant differences among the five instrument systems in total surface defect scores ($H(4) = 1.32$, $p = 0.86$). Similarly, individual defect categories, including machining grooves, pits, microcracks, protrusions, and irregularities, did not differ significantly between brands ($p > 0.05$ for all comparisons). Effect size analysis confirmed negligible intergroup differences, indicating comparable baseline surface integrity across all evaluated systems. Across all systems, most defects were minor (score 1), with very few severe defects (score 3). No instrument exhibited severe microcrack scores >1 .

Table 1. Descriptive statistics for total defect scores

Brand	n	Mean	SD	Median	Min	Max
I-File	18	3.89	0.92	3.8	2.4	5.6
Mtwo	18	3.94	0.84	3.9	2.6	5.4
Reciproc Mwire	18	3.86	0.99	3.7	2.3	5.8
Reciproc Blue	18	3.92	0.88	3.8	2.5	5.5
WaveOne Gold	18	3.95	0.89	3.9	2.7	5.6

Table 2. Defect frequency by category (mean $\pm$ SD)

Defect Type	I-File	Mtwo	Reciproc Mwire	Reciproc Blue	WaveOne Gold
Machining grooves	1.83 $\pm$ 0.37	1.78 $\pm$ 0.41	1.89 $\pm$ 0.45	1.85 $\pm$ 0.40	1.81 $\pm$ 0.39
Pits	0.78 $\pm$ 0.29	0.83 $\pm$ 0.26	0.72 $\pm$ 0.31	0.76 $\pm$ 0.30	0.80 $\pm$ 0.28
Microcracks	0.22 $\pm$ 0.15	0.28 $\pm$ 0.18	0.19 $\pm$ 0.14	0.25 $\pm$ 0.17	0.24 $\pm$ 0.16
Protrusions	0.39 $\pm$ 0.21	0.44 $\pm$ 0.20	0.36 $\pm$ 0.19	0.41 $\pm$ 0.21	0.42 $\pm$ 0.20
Irregularities	0.67 $\pm$ 0.33	0.61 $\pm$ 0.30	0.70 $\pm$ 0.35	0.65 $\pm$ 0.32	0.68 $\pm$ 0.34

Table 3. Kruskal–Wallis test results (between-group comparisons)

Variable	H statistic	df	p-value
Machining grooves	1.18	4	0.88
Pits	1.42	4	0.84
Microcracks	1.67	4	0.80
Protrusions	1.25	4	0.87
Irregularities	1.31	4	0.86
Total defect score	1.32	4	0.86

Table 4. Effect size (η^2) for Kruskal–Wallis tests

Variable	η^2 (eta squared)	Interpretation
Machining grooves	0.01	Negligible
Pits	0.02	Negligible
Microcracks	0.02	Negligible
Protrusions	0.01	Negligible
Total score	0.02	Negligible

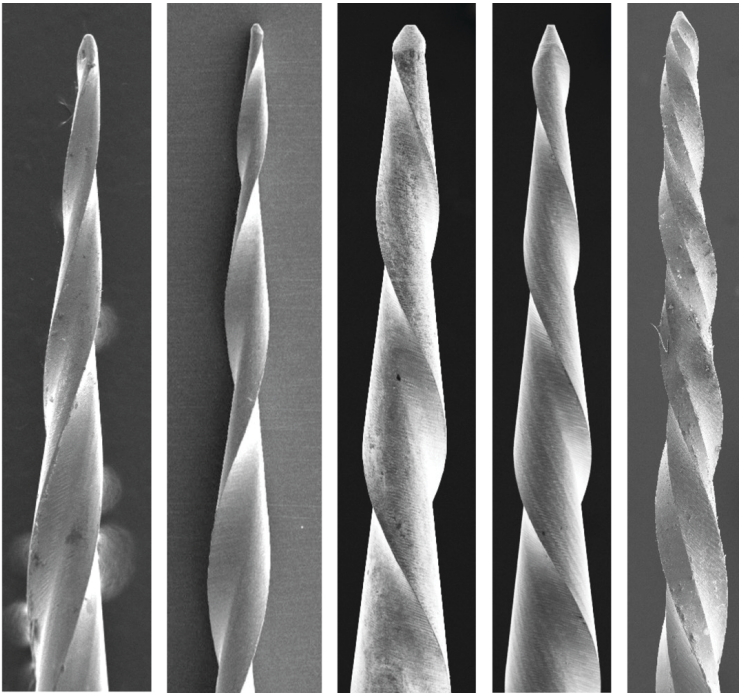


Figure 1. Blades of a specimen selected for each group from left to right I-file, Mtwo, Reciproc Mwire, Reciproc Blue, WaveOne gold.

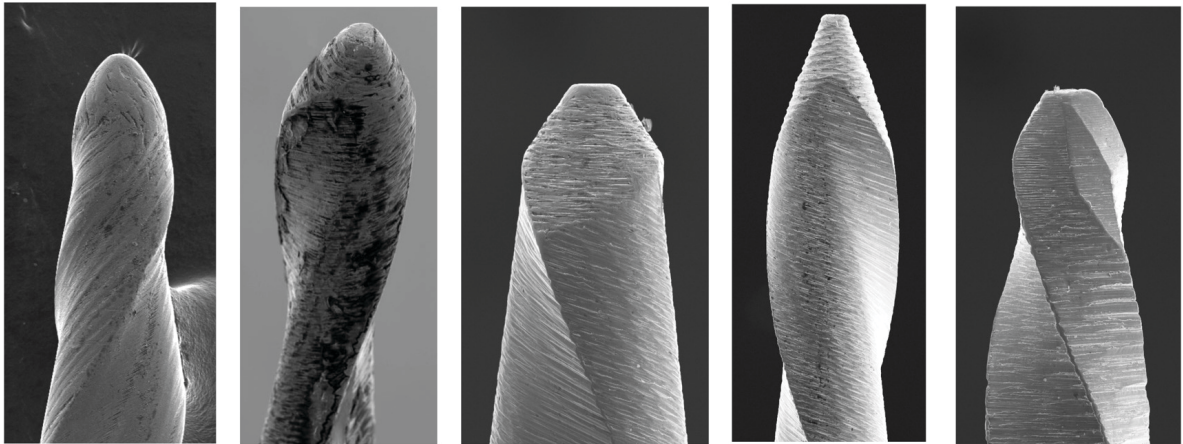


Figure 2. Tips particular of a specimen selected for each group from left to right: I-file, Mtwo, Reciproc Mwire, Reciproc Blue, WaveOne gold.

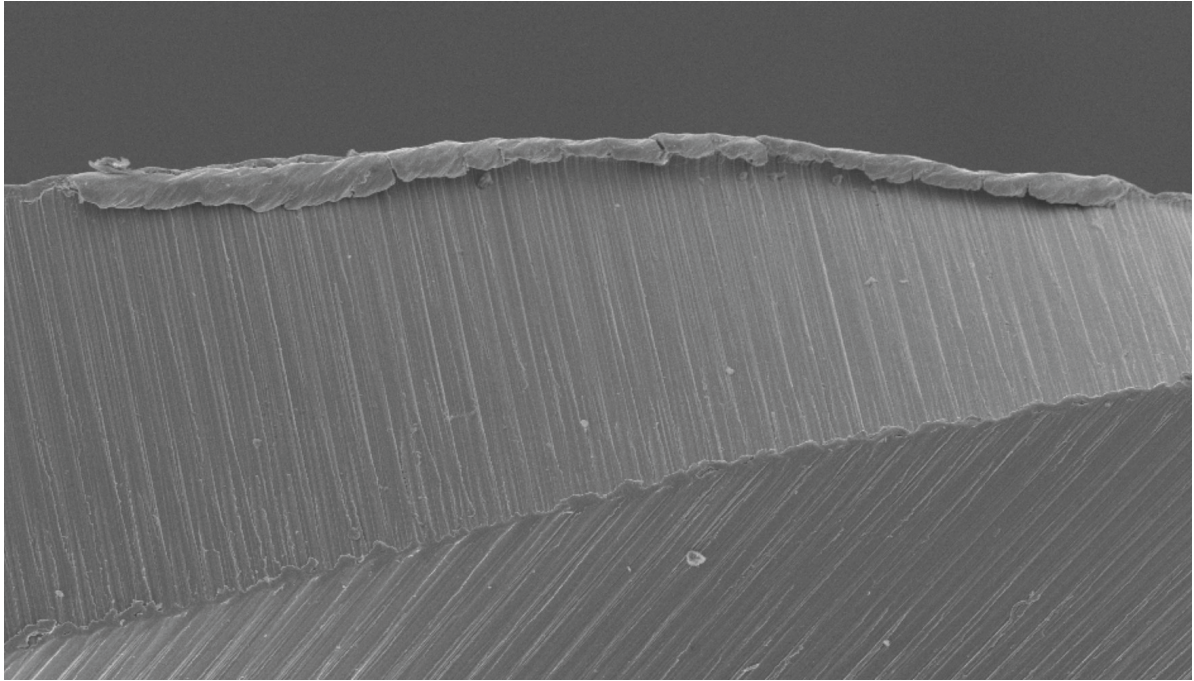


Figure 3. Example of a "Burr" on the surface of a cutting edge in the coronal third of a specimen.

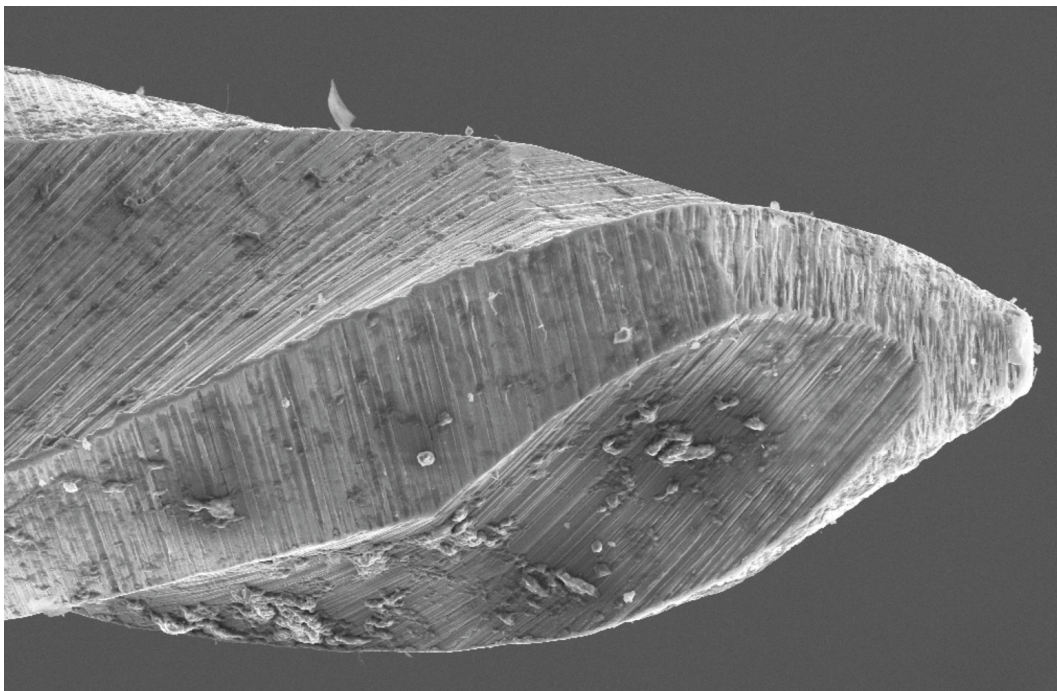


Figure 4. Example of "Milling grooves" on the tip of a specimen.

Discussion

This study quantified and compared external surface defects of five NiTi endodontic instrument brands using SEM, adopting the defect categories described by Arantes (9). The primary finding was the lack

of statistically significant differences in surface defect profiles among instruments from different manufacturers. Although defects were ubiquitous to some degree, even in new, unused files, they were predominantly minor and likely reflective of routine

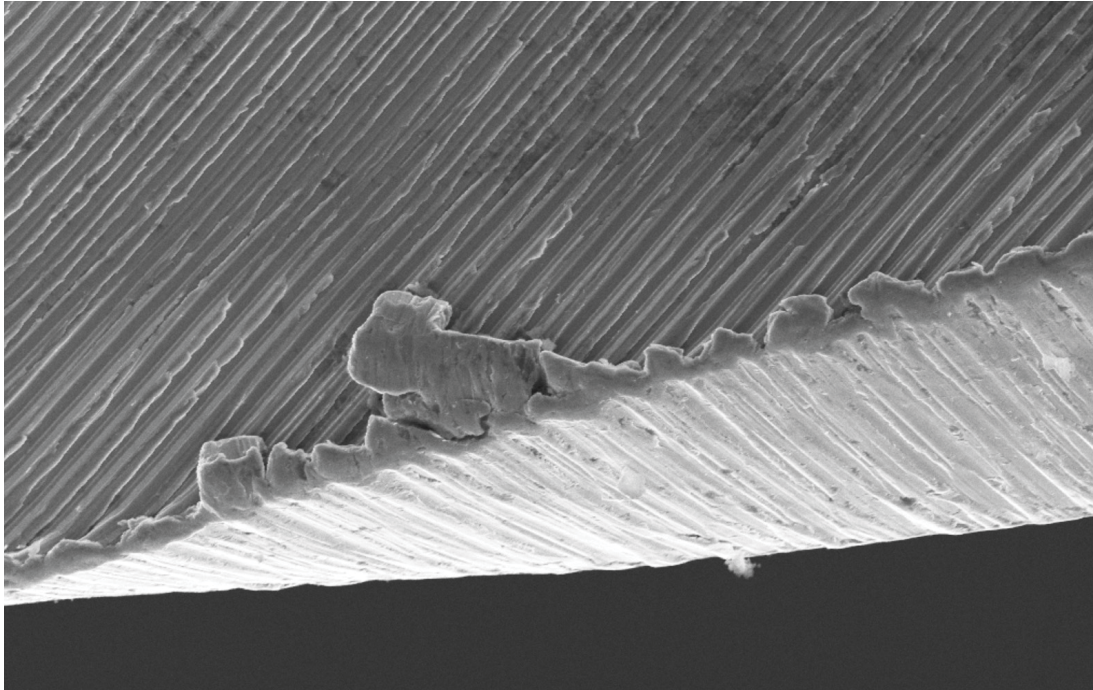


Figure 5. Example of an “Irregular Edge” on the surface of the blade in the middle third of a specimen.

manufacturing marks rather than clinically relevant flaws. This is because grinding devices may slightly change their efficiency during use and therefore require routine replacement to ensure optimal performance; a new grinding wheel is ideally better than a used one. McSpadden (2007) details how the rotary grinding process used to fabricate these instruments inevitably leaves striations and micro-imperfections on the metal surface, confirming that such marks are intrinsic to the manufacturing technique (14). Our findings partially align with those of Arantes (9), who reported surface irregularities in ground NiTi instruments, such as pits and grooves attributed to machining processes. The current study confirms that such defects remain observable in contemporary instruments across various heat treatments and alloys.

Prior investigations (15,16) have similarly noted superficial surface irregularities in brand-new NiTi files. Similarly, Pirani et al. (2016) and Kaval & Capar (2017) reported the presence of machining defects on multiple rotary systems before use, without finding a direct, immediate correlation with fatigue failure in their experimental models (17, 18).

However, some reports suggest that heat treatment can affect surface topography and fatigue resistance. For example, Blue and Gold treatments reportedly alter crystalline structure and enhance cyclic fatigue life (10, 19). In particular, Plotino et al. (2014) observed that the phase transition temperatures specific to heat treatments can influence not only flexibility but also the surface response to wear. However, the present study did not highlight significant baseline morphological differences (19).

Despite these metallurgical differences, the current

SEM analysis did not detect discernible differences in baseline surface defect prevalence. This suggests that manufacturing finishing processes, rather than heat treatment per se, may be a dominant factor in visible surface irregularities. The subsequent heat treatments, when provided, did not affect surface irregularities.

Although the presence of microdefects raises theoretical concerns regarding stress concentration and crack initiation, the predominantly superficial nature of defects observed, especially machining grooves and minor pits, suggests limited impact on in-use instrument integrity. It is relevant to note that, although Pedullà et al. (2015) demonstrated that reciprocating movements extend fatigue life compared to continuous rotation, the initial surface quality remains a common factor that could influence both kinematic types in the long term (20).

None of the defect categories exhibited severity scores commonly associated with structural weakness, and no instrument had high-grade microcracks before use. It is important to emphasize that this study evaluated new instruments before clinical use. In vivo stresses that accumulate during canal shaping are known to induce additional surface changes not captured here. Further research correlating baseline surface topography with fatigue performance and in-use failure is recommended. It is important to emphasize that this study evaluated new instruments before clinical use. In vivo stresses that accumulate during canal shaping are known to induce additional surface changes not captured here. Further research correlating baseline surface topography with fatigue performance and in-use failure is warranted.

Several limitations should be considered: while SEM provides high resolution, this analysis was limited to selected areas and magnifications. It is possible

that defects outside the imaged regions remained undetected. Moreover, despite using standardized scoring indices, subjective interpretation may have influenced severity assessments. Inter-rater reliability was not reported. A limitation is that even if common sizes were included, variations in taper and diameter across brands may have influenced defect prevalence. Future studies may integrate quantitative surface roughness measurements (e.g., profilometry) and correlate baseline topography with mechanical testing (cyclic fatigue, torsional resistance) to elucidate links between surface features and functional performance. Additionally, post-clinical evaluation could assess how initial defects evolve under operational stresses.

Conclusions

Within the limitations of this SEM analysis, the five NiTi instrument brands (I-File/Onyx, Mtwo, Reciproc Mwire, Reciproc Blue, and WaveOne Gold) demonstrated comparable external surface integrity, independent of the different grinding devices and heat treatments. Surface irregularities were present across all groups but were mostly minor, suggesting that the manufacturing quality of grinding procedures is consistent across these different metallurgical technologies. The subsequent heat treatments, when provided, did not affect surface irregularities.

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